

TU-714

Large Supersymmetric Contribution to CP Asymmetry of $B_d \rightarrow \phi K_S$ from Left-Handed Squark Mixing

Motoi Endo, Mitsuru Kakizaki and Masahiro Yamaguchi

Department of Physics, Tohoku University, Sendai 980-8578, Japan

(February 1, 2008)

Abstract

Supersymmetric contribution to the CP asymmetry of $B_d \rightarrow \phi K_S$ is re-examined. It is emphasized that our analysis takes into account the recently found constraint from the mercury electric dipole moment, in addition to the well-known constraint from the branching ratio of $b \rightarrow s\gamma$. We show that, despite these constraints, the CP asymmetry can considerably deviate from the Standard Model prediction, if the CP-odd flavor mixing comes from left-handed squarks. Alignment mechanism of sfermion masses and mixing may imprint the required flavor mixing at high energy scale.

I. INTRODUCTION

One of the most celebrated features of the Standard Model of particle physics is that the flavor changing neutral current (FCNC) is suppressed by the GIM mechanism. All contributions to the FCNC processes arise at loop level, which are further suppressed by either small mass differences between different generations or small generation mixing angles. In fact, the mixing between the first two generations is suppressed because of the small quark masses (and thus small mass differences) and the mixing containing the third generation is suppressed because of the small entries of the Cabibbo-Kobayashi-Maskawa (CKM) matrix.

Extensions of the Standard Model generically do not have such a suppression mechanism and thus tend to suffer too large FCNC. This fact gives stringent constraints on how new physics beyond the Standard Model should be. Put another way, it implies that signals of a beyond-the-Standard-Model may be revealed in flavor physics.

Nowadays a special attention is paid to the flavor mixings in B mesons. On the experimental side, B-factories are in operation, with a lot of new results on the nature of the flavor mixings of the B mesons. On the theoretical side, the fact that the quark masses are hierarchical in inter-generations implies that the third generation may be special and a new physics may manifest itself there.

Among other things, a very interesting process is $B_d \rightarrow \phi K_S$ whose CP asymmetry is measured at the B factories. Theoretically a new physics contribution may easily be seen in this process because there is no tree-level contribution in the Standard Model. The latest result of the Belle collaboration announced that the discrepancy from the Standard Model in the CP asymmetry of $B_d \rightarrow \phi K_S$ is still there [1], *i.e.*

$$S_{\phi K_S} = -0.96 \pm 0.50^{+0.09}_{-0.11}, \quad (1)$$

while that of the BaBar collaboration [2]

$$S_{\phi K_S} = 0.47 \pm 0.34^{+0.08}_{-0.06} \quad (2)$$

is consistent with the Standard Model prediction. Though the situation is yet unclear, one certainly has to watch what is happening when more data are accumulated, and on the theoretical side it is important to investigate in what situation new physics can generate large $b \rightarrow s$ transition.

Here we consider supersymmetric models, a promising framework to solve the gauge hierarchy problem. A new source of flavor mixing originates from SUSY breaking masses of squarks and sleptons. The flavor mixing between the second and third generations both in left-handed squarks (LL) and in right-handed squarks (RR) can make contribution to $B_d \rightarrow \phi K_S$. Combined with flavor-conserving left-right squark mixing which is proportional to $m_b \tan \beta$, with $\tan \beta$ being the ratio of the vacuum expectation values of the two Higgs doublets, the flavor mixing in the left-right squark mixing can also be induced.¹

¹Throughout this paper, we do not consider the direct flavor transition in the left-right squark mixing.

The flavor mixing in the RR sector can be generated by renormalization group effects of right-handed neutrino Yukawa couplings if the theory is grand unified. The implications to the CP asymmetry of $B \rightarrow \phi K_s$ and other processes were studied intensively [3–5]. More general analyses were also done in Refs. [6–12].

A notable observation has recently been made in Ref. [13], which has found that the present experimental bound on the electric dipole moment (EDM) of mercury atom severely constrains the CP violating part of a product of the LL and RR down-type squark flavor mixing between the 2nd and the 3rd generations. Radiative corrections (renormalization group effects) due to Yukawa interaction for up-type quark masses generate significant flavor mixing in the LL sector when one considers the high scale SUSY breaking scenario where the mediation of the SUSY breaking takes place at a high energy scale. Given the non-negligible mixing in the LL sector at the electroweak scale, the bound from the ^{199}Hg EDM thus practically constrains the flavor mixing in the RR sector. It has been shown that with the parameters satisfying the constraint the contribution to the CP asymmetry of the $B_d \rightarrow \phi K_S$ decay from the RR mixing is negligibly small.

We are thus led to consider the LL mixing in the squark masses as a possible source of the beauty to strange transition in the SUSY models. In a recent paper [14], we have discussed the constraint on the LL flavor mixing coming from the Hg EDM. In this case the dominant contribution is from chargino-squark loop and thus it is not as large as the gluino-squark loop contribution. Thus one expects that the SUSY contribution to the CP asymmetry of the $B_d \rightarrow \phi K_S$ decay can be considerably large even when presently known constraints including that from the Hg EDM are taken into account.

A purpose of the present paper is to quantify this prospect. We will exhibit our numerical study on the CP asymmetry of $B_d \rightarrow \phi K_S$. We emphasize that the new constraint from the Hg EDM will be taken into account, in addition to the well-known constraint from $b \rightarrow s\gamma$. We will show that the SUSY contribution to the CP asymmetry can, in fact, be large when $\tan\beta$ is large even after the constraints are imposed. We will also observe that the constraint from the Hg EDM is in general comparable to that of $b \rightarrow s\gamma$ in severity, and which of the two is more stringent depends on the parameters chosen. This illustrates the importance of the new constraint from the Hg EDM discussed in our previous paper.

II. FLAVOR STRUCTURE OF SQUARK MASSES

Before going to the flavor changing processes, we would like to briefly state the flavor structure of the squark mass matrices assumed in this paper. The soft SUSY breaking sfermion masses are given at a very high energy scale, which are driven down to low energy by renormalization group flow. The flavor violation in the sfermion masses thus has two sources: one is imprinted at the high energy scale, and the other one is due to renormalization group effects. In the minimal supergravity, there is no imprinted flavor violation in the sfermion masses, and the flavor mixing comes only from that of the Yukawa coupling matrices. In the minimal supersymmetric model, the flavor mixing arises solely in the $\text{SU}(2)_L$ doublet (left-handed) squark mass matrix (LL sector) and CP phase is proportional to the Kobayashi-Maskawa CP phase in the quark Yukawa coupling matrix. Thus in this case the SUSY contribution to the CP asymmetry of $B_d \rightarrow \phi K_S$ is not expected. On the other hand, in a grand unified theory with right-handed neutrino Yukawa couplings, the $\text{SU}(2)_L$ singlet (right-

handed) down-type squarks (RR sector) have flavor mixing as well as new CP violation. It was argued that this gives a sizable SUSY contribution to the CP asymmetry of $B_d \rightarrow \phi K_S$ [3–5]. However the CP phase would make too large a contribution to the Hg EDM unless there is unplausible cancellation between different diagrams [13].

Our hypothetical flavor-mixing with new CP phase in the $SU(2)_L$ doublet (left-handed) squarks, namely in the LL sector, is likely due to the imprinting at the ultra high energy scale, where the flavor violation of the squark masses appears from the beginning. Namely we assume that the initial soft SUSY breaking masses are given such that flavor violation arises only in the LL sector. Furthermore we assume that the renormalization group effect which causes flavor mixing solely comes from the CKM matrix. The latter implies that, in the context of GUT, either the right-handed neutrino Yukawa couplings are small or the soft masses arise below the GUT scale. We anticipate existence of alignment mechanism of quark/squark masses and mixing which realizes the required squark flavor mixing pattern, possibly due to flavor symmetry or geometry of extra dimensions. Actually the democratic sfermion mechanism advocated in Ref. [15] can give this mass pattern: the flavor mixing in the right-handed down-type squarks, which form $\bar{5}$ multiplet with left-handed (s)leptons, is argued to be absent due to non-trivial interplay with neutrino mass matrix. Here we will not pursue possible alignment mechanisms to realize this structure of the squark mass matrices any further in this paper. Rather we simply assume this structure and consider its phenomenological implications.

III. SUSY CONTRIBUTION TO $B_d \rightarrow \phi K_S$

Let us turn to SUSY contributions to $B_d \rightarrow \phi K_S$. The time dependent CP asymmetry of the $B_d \rightarrow \phi K_S$ is defined as

$$a_{\phi K}(t) = C_{\phi K} \cos(\Delta M_{B_d} t) + S_{\phi K} \sin(\Delta M_{B_d} t), \quad (3)$$

where $C_{\phi K}$ and $S_{\phi K}$ are given by

$$C_{\phi K} = \frac{1 - |\lambda|^2}{1 + |\lambda|^2}, \quad S_{\phi K} = \frac{2\text{Im}\lambda}{1 + |\lambda|^2}. \quad (4)$$

Here λ is defined as

$$\lambda = \frac{q \bar{\mathcal{A}}(\bar{B}_d \rightarrow \phi K_S)}{p \mathcal{A}(B_d \rightarrow \phi K_S)} = \frac{q}{p} \frac{(\bar{\mathcal{A}}_{\phi K}^{\text{SM}} + \bar{\mathcal{A}}_{\phi K}^{\text{SUSY}})}{(\mathcal{A}_{\phi K}^{\text{SM}} + \mathcal{A}_{\phi K}^{\text{SUSY}})}. \quad (5)$$

The ratio q/p is evaluated from the $B_d^0 - \bar{B}_d^0$ mixing and is approximately parameterized as $q/p = e^{2i\beta}$. If the decay amplitude is almost determined by the SM diagrams and there is no additional CP violation, the ratio $\bar{\mathcal{A}}/\mathcal{A}$ is real and the CP asymmetry $S_{\phi K}$ becomes the same as the one measured by the $B_d \rightarrow J/\psi K_S$ process, $S_{J/\psi K} = \sin 2\beta = 0.736 \pm 0.049$ [16,17]. The SUSY contributions to $B_d \rightarrow \phi K_S$ in the decay amplitudes is, however, generically comparable to the SM one because the latter is loop suppressed. Then the CP asymmetry $S_{\phi K}$ deviates from the value by $B_d \rightarrow J/\psi K_S$.

The $\Delta B = 1$ effective Hamiltonian which is relevant for the $b \rightarrow s$ transition is given by

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[\sum_{i=2}^6 (C_i O_i + C'_i O'_i) + C_{7\gamma} O_{7\gamma} + C'_{7\gamma} O'_{7\gamma} + C_{8g} O_{8g} + C'_{8g} O'_{8g} \right]. \quad (6)$$

where

$$\begin{aligned} O_2 &= (\bar{s}\gamma^\mu P_L c)(\bar{c}\gamma_\mu P_L b), \\ O_3 &= (\bar{s}\gamma^\mu P_L b)(\bar{s}\gamma_\mu P_L s), \\ O_4 &= (\bar{s}_i \gamma^\mu P_L b_j)(\bar{s}_j \gamma_\mu P_L s_i), \\ O_5 &= (\bar{s}\gamma^\mu P_L b)(\bar{s}\gamma_\mu P_R s), \\ O_6 &= (\bar{s}_i \gamma^\mu P_L b_j)(\bar{s}_j \gamma_\mu P_R s_i), \\ O_{7\gamma} &= \frac{e}{16\pi^2} m_b (\bar{s}_i \sigma^{\mu\nu} P_R b_i) F_{\mu\nu}, \\ O_{8g} &= \frac{g_s}{16\pi^2} m_b (\bar{s}_i \sigma^{\mu\nu} T_{ij}^a P_R b_j) G_{\mu\nu}^a. \end{aligned} \quad (7)$$

Here i and j are color indices, $P_{R,L} = (1 \pm \gamma_5)/2$. The prime expresses the exchange of L and R .

We have 5 four-quark operators and 2 dipole ones for the flavor changing process. The corresponding Wilson coefficients C_i are evaluated from the diagrams in which the the heavy SM or the SUSY particles propagate virtually. In the low energy region, these coefficients have two sources of flavor violation: the CKM matrix and squark mass matrices. The squark flavor mixings are denoted by the following squark flavor mixing parameters in the mass insertion approximation (MIA)

$$\begin{aligned} (\delta_{LL}^u)_{ij} &= \frac{(m_{\tilde{u}_L}^2)_{ij}}{m_{\tilde{q}}^2}, & (\delta_{RR}^u)_{ij} &= \frac{(m_{\tilde{u}_R}^2)_{ij}}{m_{\tilde{q}}^2}, \\ (\delta_{LR}^u)_{ij} &= \frac{(m_{\tilde{u}_{LR}}^2)_{ij}}{m_{\tilde{q}}^2}, & (\delta_{RL}^u)_{ij} &= (\delta_{LR}^{u*})_{ji}. \end{aligned} \quad (8)$$

First, we consider the flavor mixing whose origin comes from the squark mass terms. Since the RR mixing should be strongly suppressed considering the Hg EDM [13], we concentrate on the LL squark mass matrix. In MIA, we estimate the Wilson coefficients at the SUSY mass scale at the one loop level as

$$\begin{aligned} C_3(\text{SUSY}) &= \frac{\sqrt{2}\alpha_s^2}{4G_F V_{tb} V_{ts}^* m_{\tilde{q}}^2} (\delta_{LL}^d)_{23} \left[-\frac{1}{9} B_1(x) - \frac{5}{9} B_2(x) - \frac{1}{18} P_1(x) - \frac{1}{2} P_2(x) \right], \\ C_4(\text{SUSY}) &= \frac{\sqrt{2}\alpha_s^2}{4G_F V_{tb} V_{ts}^* m_{\tilde{q}}^2} (\delta_{LL}^d)_{23} \left[-\frac{7}{3} B_1(x) + \frac{1}{3} B_2(x) + \frac{1}{6} P_1(x) + \frac{3}{2} P_2(x) \right], \\ C_5(\text{SUSY}) &= \frac{\sqrt{2}\alpha_s^2}{4G_F V_{tb} V_{ts}^* m_{\tilde{q}}^2} (\delta_{LL}^d)_{23} \left[\frac{10}{9} B_1(x) + \frac{1}{18} B_2(x) - \frac{1}{18} P_1(x) - \frac{1}{2} P_2(x) \right], \\ C_6(\text{SUSY}) &= \frac{\sqrt{2}\alpha_s^2}{4G_F V_{tb} V_{ts}^* m_{\tilde{q}}^2} (\delta_{LL}^d)_{23} \left[-\frac{2}{3} B_1(x) + \frac{7}{6} B_2(x) + \frac{1}{6} P_1(x) + \frac{3}{2} P_2(x) \right], \\ C_{7\gamma}(\text{SUSY}) &= -\frac{\alpha_s \pi}{3\sqrt{2} G_F V_{tb} V_{ts}^* m_{\tilde{q}}^2} (\delta_{LL}^d)_{23} \left[\frac{8}{3} M_3(x) - \mu_H \tan \beta \frac{m_{\tilde{q}}}{m_{\tilde{q}}^2} \frac{8}{3} M_a(x) \right], \end{aligned}$$

$$\begin{aligned}
C_{8g}(\text{SUSY}) = & \frac{\alpha_s \pi}{\sqrt{2} G_F V_{tb} V_{ts}^* m_{\tilde{q}}^2} (\delta_{LL}^d)_{23} \left[\frac{8}{3} \left(-\frac{1}{3} M_3(x) - 3M_4(x) \right) \right. \\
& \left. - \mu_H \tan \beta \frac{m_{\tilde{g}}}{m_{\tilde{q}}^2} \left(-\frac{1}{3} M_a(x) - 3M_b(x) \right) \right], \tag{9}
\end{aligned}$$

where $B(x)$, $P(x)$ and $M(x)$ are the loop functions ² and $x = m_{\tilde{g}}^2/m_{\tilde{q}}^2$. And μ_H , $m_{\tilde{g}}$ and $m_{\tilde{q}}$ are the higgsino mass parameter, the gluino mass and typical squark mass, respectively. Here we consider the gluino mediated diagrams which dominate the SUSY contributions. We note here that some terms in Eq. (9) are enhanced by $\tan \beta$. These are due to double mass insertion diagrams, which contain both the (flavor violating) LL mixing and the (flavor conserving) RL down type squark mixing parameters. This type of enhancement is dominant for the Wilson coefficients which require chirality flipping, that is, $C_{7\gamma}$ and C_{8g} .

The other contributions stem from the CKM matrix. These include the SM, the charged Higgs, the chargino and the neutralino diagrams. The SM ones are estimated at the one loop order and partially at the two loop level [19]. And the charged Higgs diagrams are calculated at the two loop order [20]. The others from the SUSY particles are estimated at the one loop level, including the corrections by large $\tan \beta$ [21], [22].

We can estimate the decay amplitude of $B_d \rightarrow \phi K_S$ in terms of these Wilson coefficients. The SUSY contributions to the CP asymmetry of $B_d \rightarrow \phi K_S$ are dominated by the chromo-magnetic operator, and thus enhanced by $\tan \beta$. Here we use the naive factorization ansatz. The matrix element of chromo-magnetic moment is given by

$$\langle \phi K_S | \frac{g_s}{16\pi^2} m_b (\bar{s}_i \sigma^{\mu\nu} T_{ij}^a P_R b_j) G_{\mu\nu}^a | \bar{B}_d \rangle = \kappa \frac{2\alpha_s}{9\pi} (\epsilon_\phi p_B) f_\phi m_\phi^2 F_+(m_\phi^2), \tag{10}$$

where ϵ_ϕ , m_ϕ and f_ϕ are the polarization vector, the mass and the decay constant of ϕ meson, respectively. And $F_+(m_\phi^2)$ is the B to K transition form factor. The coefficient $\kappa = -1.1$ is estimated in the heavy-quark effective theory [5], though there is large hadronic uncertainty. Then the SUSY contributions to the $B_d \rightarrow \phi K_S$ decay amplitude depend on the LL squark flavor mixing parameter, the squark mass, $\tan \beta$ and μ_H .

The squark flavor mixing $(\delta_{LL}^d)_{23}$ is constrained by the branching ratio of $b \rightarrow s\gamma$ and the Hg EDM. The experimental value of the $b \rightarrow s\gamma$ branching ratio well agrees with the prediction by the SM. Thus the SUSY contributions have to be canceled among them. Experimentally, the branching ratio $Br(\bar{B} \rightarrow X_s \gamma)$ was measured precisely [23–27]. Here we take

$$2.0 \times 10^{-4} < Br(b \rightarrow s\gamma) < 4.5 \times 10^{-4}, \tag{11}$$

which is rather conservative in the light of various theoretical uncertainties. In the absence of the squark mixing, the amplitude from the chargino diagrams is generically comparable to those from the SM. A proper choice of sign of μ_H causes the destructive interference among the SM and the SUSY diagrams. On the other hand, the contributions from the

²The loop functions $B(x)$, $P(x)$, $M_3(x)$ and $M_4(x)$ are defined in Ref. [18]. $M_a(x)$ and $M_b(x)$ are same as $M_1(x)$ and $M_2(x)$ of Ref. [13], respectively.

imaginary part of the squark flavor mixing is always additive to the branching ratio. The electromagnetic moment in Eq. (9) dominates the branching ratio. Then the relevant parameters are $(\delta_{LL}^d)_{23}$, $\tan\beta$, μ_H and the soft masses $m_{\tilde{g}}^2$ and $m_{\tilde{q}}^2$.

The Hg EDM also gives a bound on the squark flavor mixing parameter. In fact, although the uncertainty comes from the hadron dynamics, the Hg EDM constrains the imaginary part of up type squark flavor mixing $(\delta_{LL}^u)_{23}$ generically. This is because the strange quark EDM affects the Hg EDM. The flavor mixing causes the EDM via the chargino loop. This diagram is also enhanced by $\tan\beta$. Thus the EDM is enhanced by the large LL squark flavor mixing and/or large $\tan\beta$, and decreases when squark mass is large. The Hg EDM also depends on the trilinear coupling A_t through the LR mixing rather than μ parameter, which appears in the diagram only as the charged higgsino mass and mixing. From the existing experimental data, $|d_{Hg}| < 2.1 \times 10^{-28} e \text{ cm}$ at 95% C.L. [28], we obtain the constraint on the CEDM of the strange quark [29],

$$e|d_s^C| < 5.5 \times 10^{-25} e \text{ cm}, \quad (12)$$

where the definition of d_s^C is given in Ref. [14]. In the generic situation, this bound on the left-handed up type squark mass is applied for the left-handed down type squark one,

$$(\delta_{LL}^d)_{32} \simeq (\delta_{LL}^u)_{32} + \lambda(\delta_{LL}^u)_{31} + O(\lambda^2), \quad (13)$$

with $\lambda \simeq 0.22$. Hereafter we consider the generic situation and assume $(\delta_{LL}^d)_{32} \simeq (\delta_{LL}^u)_{32}$. Then we can constrain the decay amplitude of the $B_d \rightarrow \phi K_S$. In particular, this bound from the Hg EDM becomes severer than that from $b \rightarrow s\gamma$ when μ_H is small.

With the experimental constraints given above, we study the CP asymmetry of $B_d \rightarrow \phi K_S$ numerically. In Fig. 1 and 2, the constant contours of the CP asymmetry of $B_d \rightarrow \phi K_S$ are shown. The constraints from the $b \rightarrow s\gamma$ branching ratio and the Hg EDM are also displayed on the graph. These quantities depends mainly on $(\delta_{LL}^u)_{23}$, $\tan\beta$, μ_H (and partially on A_t) and the soft masses $m_{\tilde{g}}^2$ and $m_{\tilde{q}}^2$. Here we show the result of $|(\delta_{LL}^u)_{23}| = 0.1$ and 0.2 with maximal complex phase. As a reference, we also fix the soft parameters as $m_{\tilde{g}}^2 = m_{\tilde{q}}^2 = (500 \text{ GeV})^2$ and $A_t = 500 \text{ GeV}$. And we take the other model parameters: the Wino mass $M_2 = 250 \text{ GeV}$ and the Higgs mass parameters $m_{H_d}^2 = -m_{H_u}^2 = (250 \text{ GeV})^2$. The CP asymmetry becomes large as μ_H or $\tan\beta$ increases. From Fig. 1 and 2, we perceive that the contribution from the LL mixing to $B_d \rightarrow \phi K_S$ can become as large as $S_{\phi K} \lesssim 0$.

We find that the resultant maximal difference between $S_{\phi K_S}$ and $S_{J/\psi K_S}$ is insensitive to $(\delta_{LL}^u)_{23}$. This is because $S_{\phi K_S}$ and both constraints are all controlled by the mixing parameter. The value also depends weakly on the soft masses, M_2 and m_H . We also note that since the SUSY contribution to the Hg EDM is proportional to A_t , larger A_t reduces the possible maximal value of deviation of $S_{\phi K_S}$ gradually (See Fig.1 and 2). Thus we conclude that the CP asymmetry of $B_d \rightarrow \phi K_S$ can deviate sizably from that of $B_d \rightarrow J/\psi K_S$ by the LL squark flavor mixing with the RR mixing suppressed.

Here we would like to briefly mention implications of the LL squark flavor mixing to other $b \rightarrow s$ transition processes. First let us consider $B_s^0 - \bar{B}_s^0$ mixing. The dominant diagram of the SUSY contribution is not enhanced by $\tan\beta$ and μ_H and depends only on the LL squark flavor mixing parameter. Thus the effect from SUSY particles is expected to be small. For $|(\delta_{LL}^u)_{23}| = 0.2$ and $m_{\tilde{g}}^2 = m_{\tilde{q}}^2 = (500 \text{ GeV})^2$, the SUSY contribution to B_s

mixing is about $\Delta M_{B_s}|\text{SUSY} \simeq 2\text{ps}^{-1}$, which may be too small to be identified as a signal of new physics at Tevatron Run II. We have also checked the effect on the CP asymmetry of $b \rightarrow s\gamma$. We expect the CP asymmetry to be at most 8%, which may marginally be seen at the on-going experiments.

IV. SUMMARY

In this paper, we revisited the SUSY contribution to the CP asymmetry of $B_d \rightarrow \phi K_S$, in the light of the recently found constraint from the mercury EDM. Ref. [13] had pointed out that the flavor mixing of the squarks in the RR sector receives a very severe constraint from the mercury EDM, provided that the 2nd and 3rd generation mixing in the LL sector is generated non-zero by renormalization group effect from the quark Yukawa couplings. Thus the flavor mixing in the RR sector will not give significant contribution to the $B_d \rightarrow \phi K_S$ CP asymmetry, unless the constraint from the mercury EDM is ameliorated by accidental cancellation. This argument allows for the flavor mixing in the LL sector to be practically the only source to generate sizable effect to the CP asymmetry. In our recent paper [14], we pointed out that the 2nd-3rd generation mixing in the LL sector is still constrained by the mercury EDM, but much less than the previous case. Combined with the well-known constraint from $Br(b \rightarrow s\gamma)$, we identified the allowed region of the parameter space, and showed that, in the allowed region, the CP asymmetry to $B_d \rightarrow \phi K_S$ can sizably deviate from the Standard Model prediction.

The origin of the flavor mixing in the LL sector is speculated as the alignment mechanism of quark/squark mass matrices. It is interesting to point out that the democratic sfermion masses considered in [15] can provide the desired flavor structure for the squarks. Attempts to seek for other possible alignment mechanisms based on flavor symmetry or geometry of extra dimensions should be encouraged.

ACKNOWLEDGMENT

This work was supported in part by the Grants-in-aid from the Ministry of Education, Culture, Sports, Science and Technology, Japan, No.12047201 and No.14046201. ME and MK thank the Japan Society for the Promotion of Science for financial support.

REFERENCES

- [1] K. Abe *et al.* [Belle Collaboration], Phys. Rev. Lett. **91** (2003) 261602.
- [2] B. Aubert *et al.* [BABAR Collaboration], arXiv:hep-ex/0403026.
- [3] T. Moroi, Phys. Lett. B **493**, 366 (2000).
- [4] D. Chang, A. Masiero and H. Murayama, Phys. Rev. D **67**, 075013 (2003).
- [5] R. Harnik, D. T. Larson, H. Murayama and A. Pierce, arXiv:hep-ph/0212180.
- [6] S. Khalil and E. Kou, Phys. Rev. D **67**, 055009 (2003).
- [7] G. L. Kane, P. Ko, H. b. Wang, C. Kolda, J. H. Park and L. T. Wang, arXiv:hep-ph/0212092; Phys. Rev. Lett. **90**, 141803 (2003).
- [8] M. Ciuchini, E. Franco, A. Masiero and L. Silvestrini, Phys. Rev. D **67**, 075016 (2003) [Erratum-ibid. D **68**, 079901 (2003)].
- [9] S. Baek, Phys. Rev. D **67**, 096004 (2003).
- [10] T. Goto, Y. Okada, Y. Shimizu, T. Shindou and M. Tanaka, arXiv:hep-ph/0306093.
- [11] R. Arnowitt, B. Dutta and B. Hu, Phys. Rev. D **68**, 075008 (2003).
- [12] M. Ciuchini, A. Masiero, L. Silvestrini, S. K. Vempati and O. Vives, Phys. Rev. Lett. **92** (2004) 071801.
- [13] J. Hisano and Y. Shimizu, Phys. Lett. B **581** (2004) 224.
- [14] M. Endo, M. Kakizaki and M. Yamaguchi, Phys. Lett. B **583** (2004) 186.
- [15] K. Hamaguchi, M. Kakizaki and M. Yamaguchi, Phys. Rev. D **68** (2003) 056007.
- [16] K. Abe *et al.* [Belle Collaboration], arXiv:hep-ex/0308036.
- [17] B. Aubert *et al.* [BABAR Collaboration], Phys. Rev. Lett. **89** (2002) 201802.
- [18] F. Gabbiani, E. Gabrielli, A. Masiero and L. Silvestrini, Nucl. Phys. B **477** (1996) 321.
- [19] G. Buchalla, A. J. Buras and M. E. Lautenbacher, Rev. Mod. Phys. **68** (1996) 1125.
- [20] M. Ciuchini, G. Degrassi, P. Gambino and G. F. Giudice, Nucl. Phys. B **527** (1998) 21; F. M. Borzumati and C. Greub, Phys. Rev. D **58** (1998) 074004.
- [21] G. Degrassi, P. Gambino and G. F. Giudice, JHEP **0012** (2000) 009; M. Carena, D. Garcia, U. Nierste and C. E. M. Wagner, Phys. Lett. B **499** (2001) 141.
- [22] F. Borzumati, C. Greub and Y. Yamada, Phys. Rev. D **69** (2004) 055005.
- [23] R. Barate *et al.* [ALEPH Collaboration], Phys. Lett. B **429** (1998) 169.
- [24] S. Chen *et al.* [CLEO Collaboration], Phys. Rev. Lett. **87** (2001) 251807.
- [25] K. Abe *et al.* [Belle Collaboration], Phys. Lett. B **511** (2001) 151; P. Koppenburg *et al.* [Belle Collaboration], arXiv:hep-ex/0403004.
- [26] B. Aubert *et al.* [BABAR Collaboration], arXiv:hep-ex/0207074; B. Aubert *et al.* [BaBar Collaboration], arXiv:hep-ex/0207076.
- [27] C. Jessop, SLAC-PUB-9610.
- [28] M. V. Romalis, W. C. Griffith and E. N. Fortson, Phys. Rev. Lett. **86** (2001) 2505.
- [29] T. Falk, K. A. Olive, M. Pospelov and R. Roiban, Nucl. Phys. B **560** (1999) 3

FIGURES

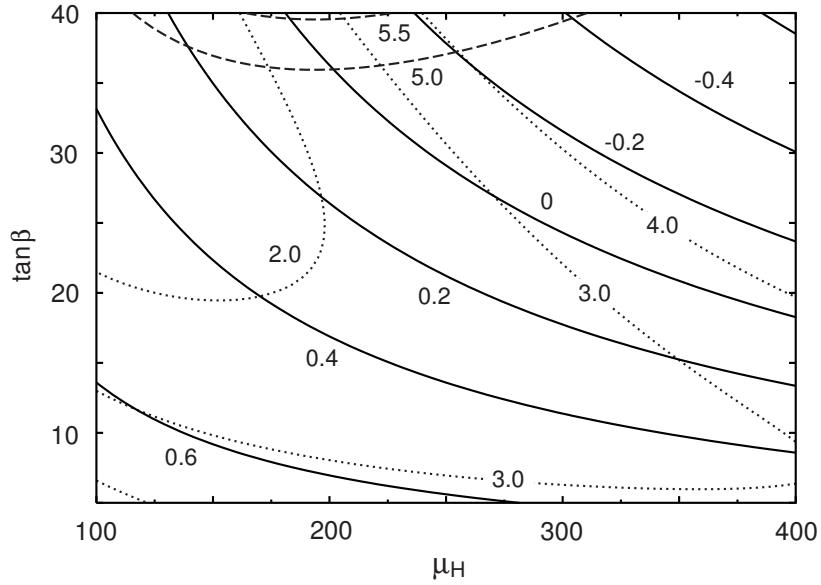


FIG. 1. Constant contours of the CP asymmetry $S_{\phi K_S}$ (solid) when the LL down-type squark mixing is $|(d_{LL}^d)_{23}| = 0.1$ with maximal phase. The contours of the $b \rightarrow s\gamma$ branching ratio (dotted, in units of 10^{-4}) and the CEDM of the strange quark which is constrained from the Hg EDM (dashed, 5.0 and 5.5 in units of 10^{-25}) are also shown. The soft parameters are $m_g^2 = m_{\tilde{q}}^2 = (500 \text{ GeV})^2$ and $A_t = 500 \text{ GeV}$.

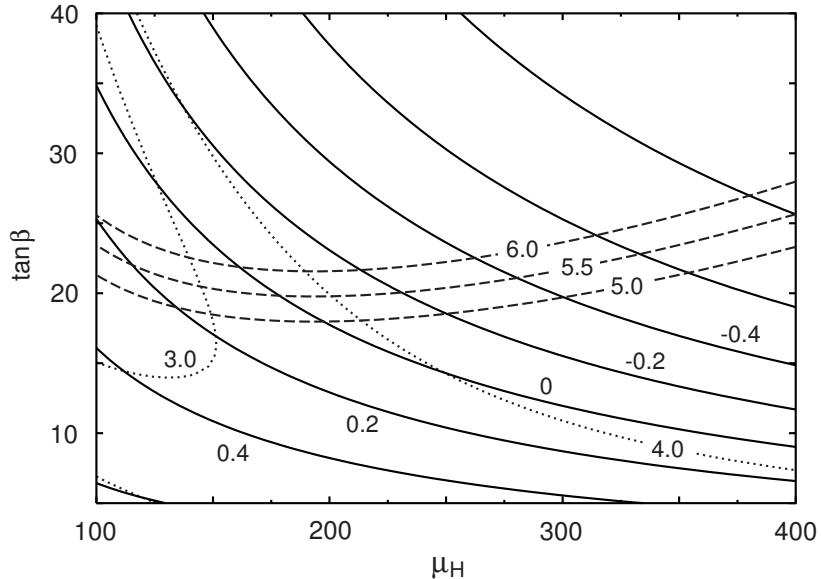


FIG. 2. Same as Fig. 1 but $|(d_{LL}^d)_{23}| = 0.2$.